

# CONCEPTS IN DISTRIBUTED SCHEDULING AND CONTROL

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## **ABSTRACT**

To support instrument and experiment operations effectively in the Space Station era, planning, scheduling and control must allow for:

- o interactive, realtime, remote operations;
- o responsive scheduling and rescheduling;
- o support of the full range of distributed science, application and commercial users;
- o interaction and cooperation among distributed users; and
- o efficient use of on-board, communications, and ground-based resources.

We suggest conceptual and managerial approaches that address these needs.

Specifically, we describe an approach to distributed planning, scheduling and control functions that is based on resources and on a distributed knowledge hierarchy. We describe these functions as components of an integrated management system. We discuss automated scheduling assistants and integration of planning and scheduling functions with realtime operations control.

The suggested approach, taken from a users' point-of-view, has resulted in the Science User Resource Planning and Scheduling System (SURPASS). In this paper, we describe the major components of SURPASS and discuss the features of this innovative prototype. Further ideas concerning instrument planning, scheduling, and control may be found in the Space Station Instrument Control System Study (Reference 1).

## INTRODUCTION

The space station era will open new and unique opportunities by making the environment of space accessible to a large community of scientists as a scientific laboratory. Some aspects of this space laboratory include low gravity environment, low pressure, no atmospheric attenuation, the ability to make global observations and complete celestial viewing. A noteworthy aspect of this space laboratory is the large separation between the scientists on the ground and their in-space experiments. To assist the scientist in interacting with their far off laboratory, an approach called "telescience" will be used. Telescience takes advantage of telecommunication services to allow scientists to remain at their home institutions where they can fully interact with their in-space experiments; where they can fully participate in planning, scheduling, controlling, evaluating and refining these experiments; and where they can work along side their research colleagues and students.

Supporting technologies and several new concepts in distributed scheduling and control need to be developed and demonstrated in order to fully support this distributed laboratory environment. These concepts are shown in the facing bullet chart.

## ORGANIZATION OF THE PAPER

We begin by describing previously proposed approaches to planning and scheduling by distributed users. Next, we discuss the work being performed at the University of Colorado in distributing instrument scheduling and control. This discussion focuses on the Science User Resource Planning and Scheduling System (SURPASS), a knowledge based prototype supported by Goddard Space Flight Center and the Strategic Plans and Programs Division of the Office of Space Station. After a description of SURPASS, we present conclusions based upon our initial work.

## CONCEPTS SUPPORTING THE DISTRIBUTED LABORATORY ENVIRONMENT

- o Provide for interaction between user scientists and their remote experiments.
- o Support scientists and commercial users involved in a wide range of applications.
- o Enable scheduling and rescheduling of experiment activities by distributed science users.
- o Make efficient use of on-board resources and promote optimal scheduling of these resources.
- o Allow the user scientist to quickly reschedule activities to react to science opportunities or problems.
- o Allow the science and applications users to work at their home institutions.

## PREVIOUS APPROACHES

In the past, a number of systems have been proposed that address planning and scheduling by distributed users. These systems were largely based on a centralized planning and scheduling hub with remote scientists placing requests on a single large global database via communications networks. Figure 1 conceptually illustrates the centralized scheduling approach.

Typically, in these proposed centralized scheduling approaches, users make requests for an experiment to be initiated at a specific time to make a specific observation. The resultant schedule to support these multiple user requests is only assembled after all these requests are received at the central hub. These requests are usually required several days to several months before the schedule is to be generated and executed, in order to allow sufficient time for constraint checking and activity scheduling. This large lead time makes it difficult, often impossible, to reschedule experiments on short notice. This inflexibility prevents experimenters from refining their experiments based on progress or responding to unexpected events. Inflexibility is both an attribute associated with centralized planning and scheduling and a characteristic of the centralized scheduling systems we have examined.

In direct contrast to the inflexibility of the planning and scheduling support, scientific instrumentation has been progressing to allow for more flexibility. Smart instruments, with embedded microprocessors, have or are expected to soon become the standard. The embedded microprocessors extend instruments' capabilities and allow an experiment to adapt to experiment findings or external conditions. These microprocessors also protect the instrumentation by automatically responding to anomalies or out-of-tolerance conditions. These more flexible and responsive instruments need planning, scheduling and control systems that support their evolving needs and capabilities.

# CENTRALIZED SCHEDULING APPROACH

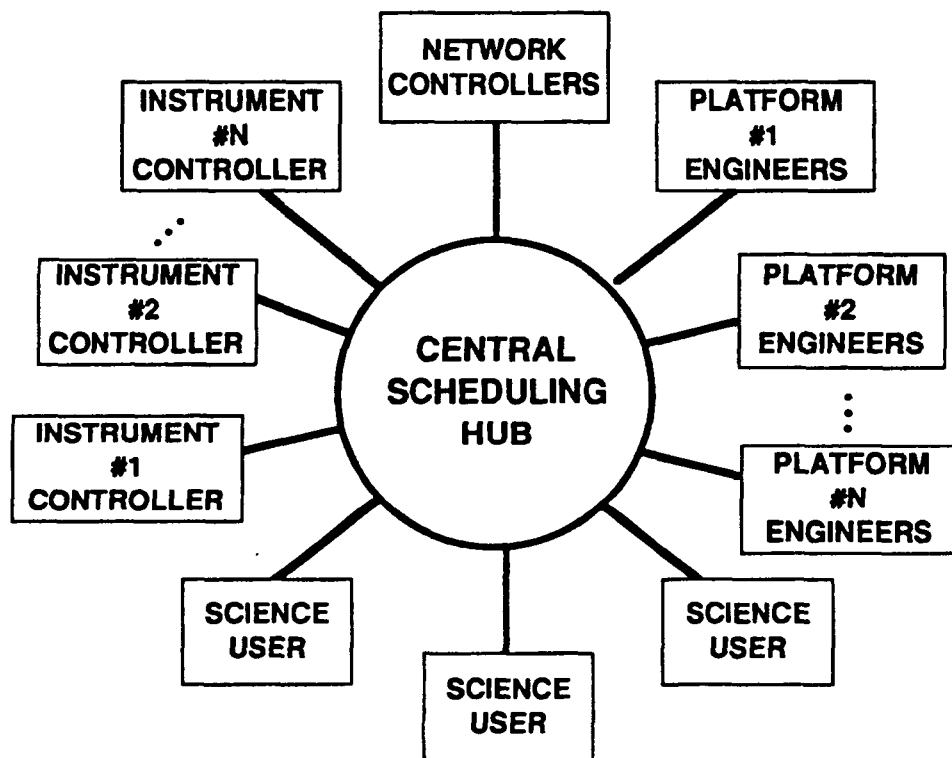


Figure 1

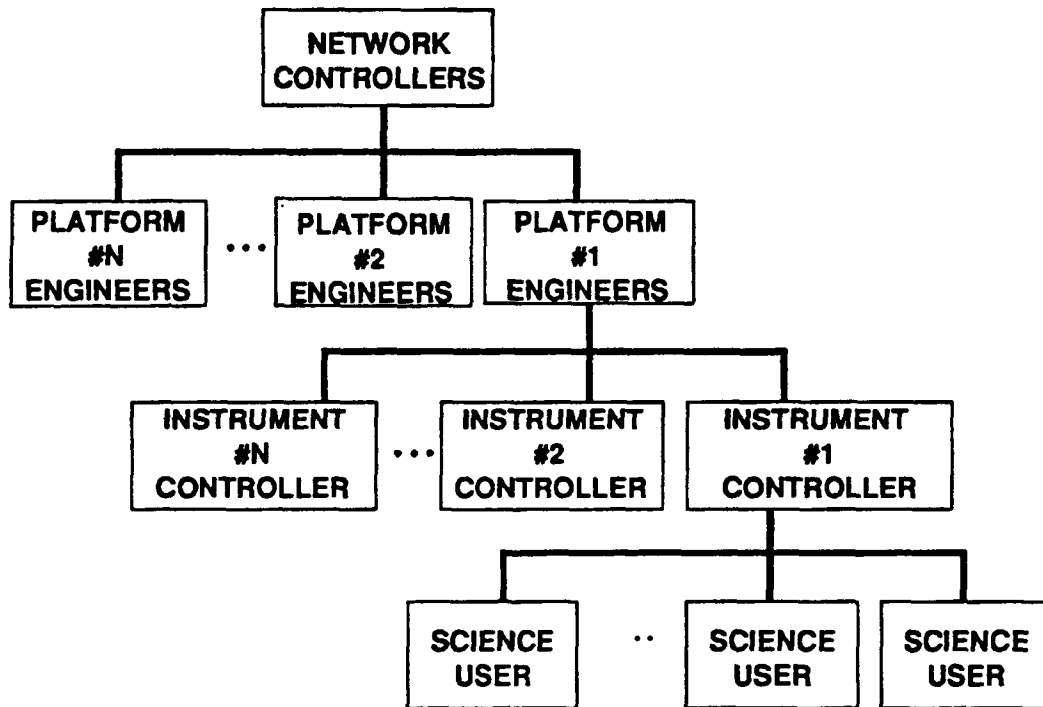
## DISTRIBUTED SCHEDULING AND CONTROL

Work at the University of Colorado has centered around distributing the scheduling and control activity among many geographically distributed nodes. In the evolving concept, each node is responsible for scheduling those activities with which it is most concerned. Individual science users are each responsible for developing a schedule of their own science experiments. The engineers at a platform support facility are responsible for scheduling platform activities such as attitude maneuvers, battery operations, and tape recorder maintenance. Similarly, controllers of communications services are responsible for scheduling these resources.

The geographically distributed nodes are arranged in such a way that they form a hierarchy that is leveled according to the physical systems which accomplish the goal. An illustration of this type of leveling is shown in Figure 2. In this hierarchical representation, the controllers of communications and tracking services, who are responsible for supporting a range of space missions, are at the top of the hierarchy. At the next lower hierarchical level are the engineers responsible for the platforms. Below them are the scientists and engineers responsible for the health and performance of the science instruments. At the lowest level of this conceptual hierarchy are the research scientists, who have the responsibility for the experiment program. At each level, and at each node in this hierarchy, local schedule optimization is accomplished using the knowledge present at that level and the predicted availability of the resources that will support the scheduled activities. In this distributed arrangement, rescheduling can be accomplished quickly when a change is requested that does not require rescheduling at the global level.

To support communications among the distributed scheduling nodes in this hierarchy, a common "language" is needed. This language needs to be able to flexibly and comprehensively communicate scheduling opportunities and user requests. The University of Colorado and Goddard Space Flight Center have developed the Flexible Envelope Request Notation (FERN), a prototype scheduling applications interface language (Reference 2) that addresses this need.

# DISTRIBUTED SCHEDULING APPROACH



## SCHEDULING HIERARCHY

Figure 2



## PROTOTYPE TOOLS

Over several years, the researchers at the University of Colorado's Laboratory for Atmospheric and Space Physics (LASP) have developed a set of prototype tools to help demonstrate how physically separated science teams will participate in planning and scheduling activities. The first phase of this work was part of the Telescience Implications on Ground Systems (TIGS), a Code T-funded study performed with the Data Systems Technology Division at Goddard Space Flight Center. This study was completed in early 1988. It was primarily concerned with the problems of communicating resource needs and opportunities among distributed nodes.

## SURPASS

The second phase, which has just started, is focused on the design and development of a knowledge based Science User Resource Planning and Scheduling System, (SURPASS). This prototype will be integrated into the Scheduling Concepts, Architectures, and Networks testbed at Goddard Space Flight Center. Use of SURPASS in this testbed will demonstrate the distributed planning, scheduling, communications, and operations management concepts. Figure 3 shows the three components of SURPASS: an expert system scheduling aid, Science User Resource Expert (SURE), an adaptable user interface that can easily be tailored to the science user's picture of the scheduling activity, and a Planning and Scheduling System manager (PASS).

SURPASS is designed to enable the remote user scientist to fit into the planning and scheduling hierarchy while maintaining the fidelity of planning and optimizing his or her experiment activities based on local scientific goals and considerations. The user interface allows the user to schedule within the appropriate scientific context and is adaptable to ensure that the SURPASS interface is consistent with other data system interfaces used by the scientist. SURE aids the user scheduling experiment activities to take optimal advantage of the available resources and still fit within resource constraints. PASS buffers complex data structures and handles communications, transactions, and interfaces.

# SCIENCE USER RESOURCE PLANNING AND SCHEDULING SYSTEM (SURPASS)

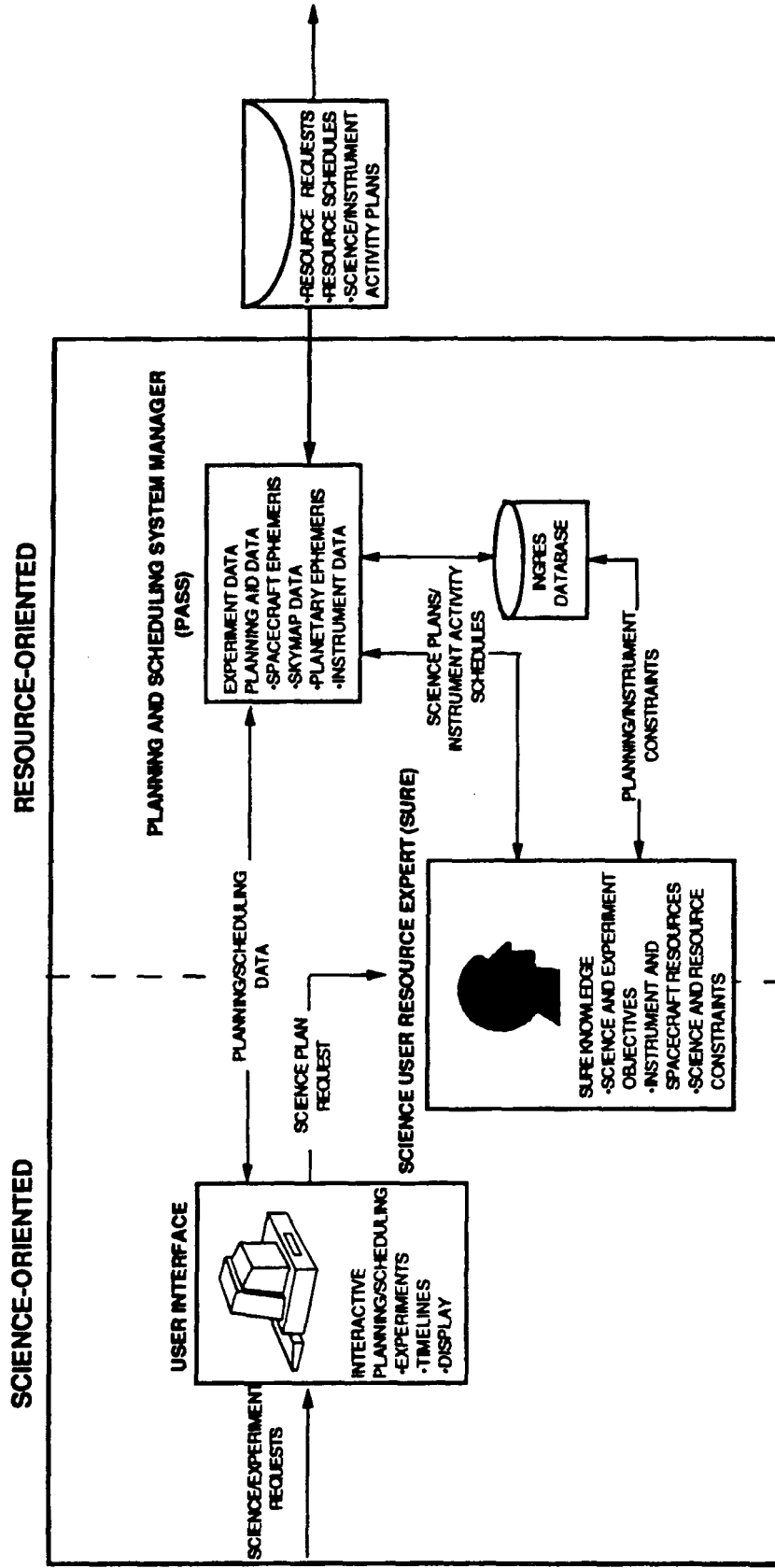


Figure 3.

Starting from an initial allocation of platform/spacecraft resources, the expert planner, SURE, builds an experiment plan based upon broad science goals and detailed relations of instrument activities and resource needs. Figure 4 provides examples of the experiment activity and resource usage which SURE attempts to maximize. SURE does not, however, have the more extensive knowledge needed to change science objectives. This is supplied by the science user.

The current prototype schedules experiment activities for the SOLSTICE instrument to be flown on the UARS mission. In this prototype, SURE generates an initial plan with a feasible acquisition sequence for a set of candidate stars selected according to the rules provided. To illustrate its performance, the time to generate a one day plan by exhaustive search required some 40 hours. Use of the SURE system with heuristics reduced the time to schedule a 24 hour day to only 15 minutes.

The output from the expert planner is displayed by SURPASS in terms of science coverage rather than the individual resources needed. The user scientist may then adjust the science plan by adding or modifying experimental activities. The SURE system calculates resource changes, checks constraints, and attempts to fit the activity into the timeline. SURE notifies the user if the activity plan cannot be inserted due to resource or constraint conflicts.

As an aid to conflict resolution, several windows providing additional information may be dynamically requested by the user. These windows inform the user of what constraint is being violated or what resource is insufficient and should be re-negotiated.

SURPASS generates schedule requests through the Planning and Scheduling System (PASS) manager. The PASS manager uses the scheduling applications interface language to communicate instrument activity requests to a platform resource scheduler in terms of resource envelopes. Complex data structures are hidden from the user by the PASS manager and maintained within the INGRES database management system. This software translates inputs into internal SURPASS data structures and internal data structures into outputs in the scheduling applications interface language.

# SOLSTICE/SSPP Resource Usage 1992/033

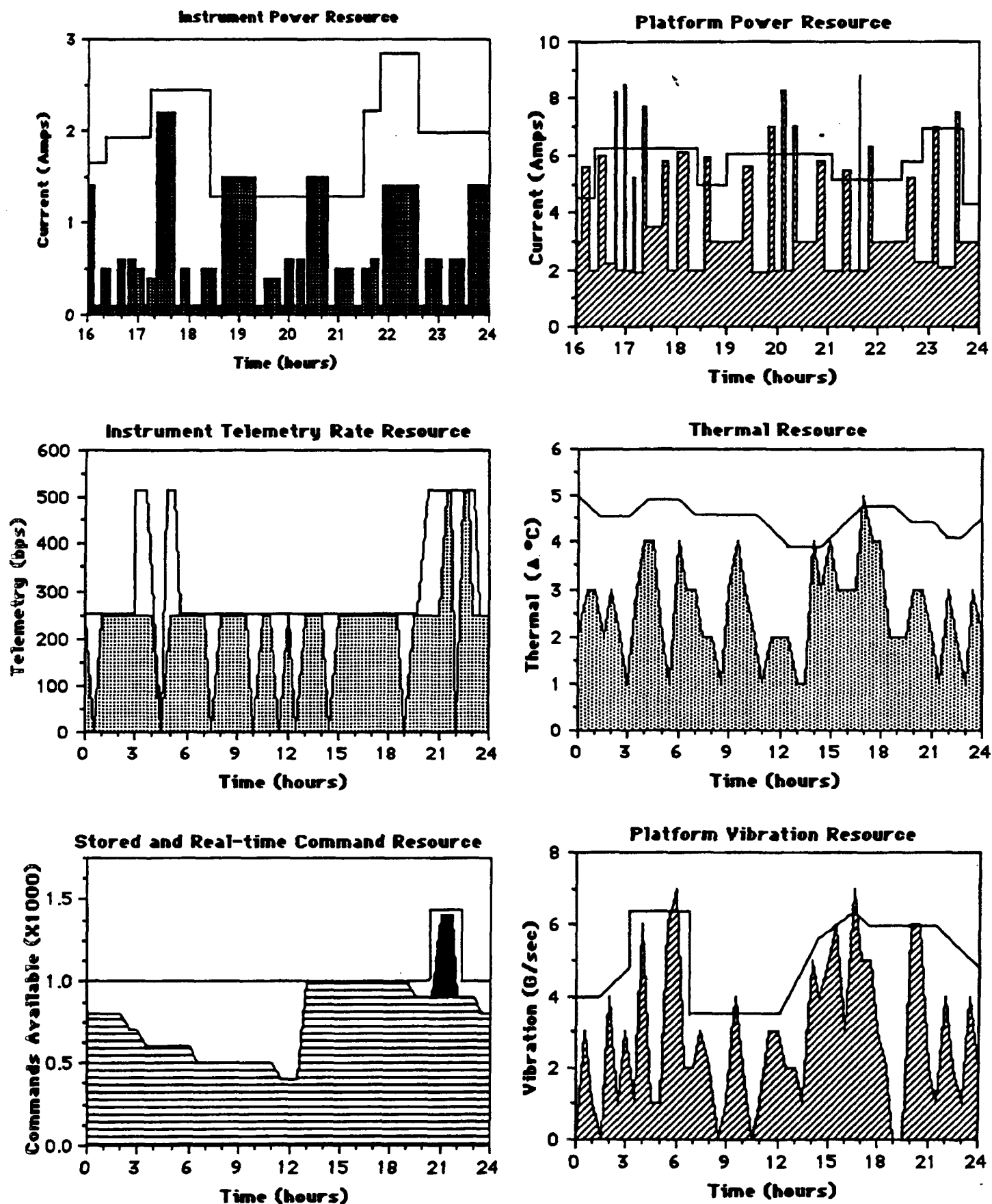


Figure 4.

## CONCLUSIONS

This research deals with the broad scope of the scheduling and control problem with its large and changing number of users, the large number of experiment plans that must be integrated each day, and the need for scientific flexibility and evolution. Some initial conclusions are summarized below:

- o Science is an exploratory activity. The scientific method, whether the investigation takes place in a small room or in a large distributed laboratory or in space, is an interactive process wherein the experimenter continually refines the investigation based on experiment findings and external changes.
- o Science users can plan and schedule instrument activities with respect to their own scientific goals. These goals can be translated into resource requests.
- o Expert systems and knowledge based tools are ideal for generating a science experiment schedule which satisfies science observing objectives, complies with rules and constraints, and remains within the available schedule of resources.
- o A distributed scheduling system with local scheduling at each node by interested, knowledgeable users is both possible and valuable.
- o Breaking down the scheduling problem into levels, and nodes within each level, the subset of the scheduling problem becomes tractable. This approach allows knowledgeable users to resolve the planning and scheduling issues locally and reschedule activities without affecting the scheduled activities of other nodes.
- o A common scheduling applications interface language is needed to be able to flexibly and comprehensively communicate scheduling opportunities and user requests among the many physically separate scheduling nodes.

## CONCLUSIONS

- Science is an exploratory activity
- Science users can plan and schedule instrument activities with respect to their own scientific goals
- Expert systems and knowledge based tools are ideal for generating a science experiment schedule
- A distributed scheduling system is both feasible and desirable
- Subdivided, the scheduling problem becomes tractable
- A common scheduling applications interface language is necessary

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## REFERENCES

1. Data Systems Technology Laboratory, "Space Station Instrument Control System Study, DSTL-89-013, November 1989.
2. Data Systems Technology Laboratory, "User's Guide For The Flexible Envelope Request Notation (FERN)", DSTL-89-015, September 1989.
3. Laboratory for Atmospheric and Space Physics, University of Colorado, Ford Aerospace Corporation, Goddard Space Flight Center, Data Systems Technology Division, "Interface Control Document for the Telescience Implications on Ground Systems (TIGS) Joint Effort", January 1988.
4. Hansen, Elaine, Sparn, Thomas, Davis, Randal, "Concepts for Planning and Scheduling in the Space Station Era", Laboratory for Atmospheric and Space Physics, University of Colorado, Boulder, Colorado, May 1988.
5. Hansen, Elaine, "Requirements for Space Station Telescience: Command, Control, and User Interface Technologies", Laboratory for Atmospheric and Space Physics, University of Colorado, Boulder, Colorado, August 1986.
6. Hansen, Elaine, Davis, Randy, Faber, Jack, Jouchoux, Alain, Ludwig, George, "Telescience Testbed Program Results", OIS 89-1, Laboratory for Atmospheric and Space Physics, University of Colorado, Boulder, Colorado, March 1989